PhD PROJECT PROPOSAL

## **PhD Project Title**

Topology-enhanced lanthanide surfaces for luminescence detection

## **PhD Supervisory Team**

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## **Project Abstract**

This interdisciplinary project will explore novel designs of plasmonic surfaces based on

defined topologies to optimise the plasmonic effect on lanthanide luminescence.

Lanthanides have attractive luminescent properties, with a characteristic fingerprint

luminescence signal which has long lifetimes and narrow bandwidth. The near infra red

emitting lanthanides, Yb, Nd, Er have characteristic profiles which range from 900 nm to

1500 nm. In the project we will design plasmonic surfaces to enhance lanthanide

luminescence. Surface modelling will assist for defined topologies using designed

lanthanide emitters. These photonic systems will bring a paradigm shift in integrated

photonic systems for optical communications and healthcare.

## **Detailed Project Description**

*Research background*

Interaction of light with interfaces is very important in optics. At an interface, light

experiences reflection, refraction at a smooth surface, or scattering and diffraction if the

surface is structured. In addition, light can be guided at the interface between two media

of certain properties, such as metal and dielectrics. These are some of the most

fundamental optical processes in optics that form the basis for most of the practical

optical devices. Most metasurfaces developed are passive devices that operate on light

coming from external light sources. However, it is anticipated that active metasurfaces

with integrated light emitters will enable broader applications. Appropriately designed

plasmonic metasurfaces provide an attractive platform to attach active emitters and

modulate light properties. They can not only enhance the photoluminescience of

integrated emitters through the Purcell effect (i.e. increased spontaneous emission due

to enhanced optical density of states), but also provide powerful control over the

direction and polarization state of the emitted light. Computational designs are employed

to optimise surface structural features to enhance the plasmonic effect. Topological

Optimisation (or Inverse Design) is a computational design approach for discovering

optical structures based on specified functional characteristics. The technique is currently

revolutionising the field of nanophotonics by allowing for the algorithmic design of

photonic devices such as filters, couplers, splitters and diplexers. A summary of this work

can be found in [1].

Lanthanides have attractive luminescent properties, with a characteristic fingerprint

luminescence signal which has long lifetimes and narrow bandwidth. The near infra red

emitting lanthanides, Yb, Nd, Er have characteristic profiles which range from 900 nm to

1500 nm (Scheme 1). Their applications in photonic devices is limited from the low

quantum yield of emission due to their poor absorption characteristics.



Scheme 1. Luminescence spectra of lanthanide emitters in the visible and near-IR.

*Outcomes*

The studies will develop novel plasmonic surfaces with lanthanide luminescent signals

enhanced by the structural designs. A modelling methodology for topological design of

the surfaces will be developed for both visible and near-infra red emitting lanthanides.

*Methodology*

Lanthanide emitter complexes will be designed based on previous expertise, using surface

active groups to covalently attach the lanthanide complexes on surfaces [2-4]. The

computational modelling will be based on commercial full-wave electromagnetic software

like Ansys Lumerical and Comsol Multiphysics, and plasmonic surfaces will be accordingly

be prepared using nano and photolithography techniques (Scheme 2).



Scheme 2. Schematic representation of plasmonic surface with lanthanide emitters.

Photophysical studies on surfaces will be evaluated using time-resolved and luminescence

spectroscopy based on a state of the art spectroscopy setup coupled to microscope for

imaging.

*An ideal/acceptable undergraduate background*

The project isideal for a student who holds an undergraduate degree in Chemistry with

strong background and interest in Physical chemistry (experimental or computational).

The student should have strong interdisciplinary interests and communication skills to

liaise within the chemistry and physics groups.

*Skills to be developed*

During the course of the PhD programme the student will develop valuable skills and

knowledge in preparation of lanthanide emitters, photophysical studies, writing code and

performing numerical computations using high performance computing, device design,

fabrication and test measurement.

*Links with research in the research groups of the supervising team*

The teams have collaborated in a DSTL funded project of near IR emitting complexes on

commercially procurred gold surfaces. A manuscript is in preparation. The team is also

drafting research proposal for further PDRA funding.

This project will benefit from close synergy with the EU funded H2020 Rise “Non-

Conventional Wave Propagation for Future Sensing & Actuating Technologies” project and

the EPSRC UK Metamaterials network led by the University of Exeter - the proposed PhD

project falls within the remit of both of them.

References

[1] S. Molesky *et al*, Nature Photonics, 12, 2018,

https://www.nature.com/articles/s41566-018-0246-9

[2] D. Davis, Z. Pikramenou et al *Inorganic Chemistry*, 2019, 58, 13268−13275.

[3] A. P. Bassett, Z. Pikramenou et al. *Journal of the American Chemical Society,* 2004,

126**,** 9413-9424.

[4] A. Davies, Z. Pikramenou et al. *Proceedings of the National Academy of Sciences of the*

*United States of America* 2012*,* 109**,** 1862-1867.